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Manufacturing Ultra-Precision Meso-scale Products by Coining

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Abstract

A method for replicating ultra-precision, meso-scale features onto a near-net-shape metallic blank has been demonstrated. The "coining" technology can be used to imprint a wide range of features and/or profiles into two opposing surfaces [1-2]. The instrumented system provides the ability to measure and control the product thickness and total thickness variation (TTV). The coining mechanism relies on kinematic principles to accurately and efficiently produce ultra-precision work pieces without the production of by products such as machining chips, or grinding swarf while preserving surface finish, material structure and overall form. Coining has been developed as a niche process for manufacturing difficult to machine, millimetre size components made from materials that may present hazardous conditions. In the case described in this paper a refractory metal part, tantalum (Ta) was produced with 4 µm peak to valley 50 µm special wavelength sine wave coined into the surface of 50 µm blank. This technique shows promise for use on ductile materials that cannot be precision machined with conventional single crystal diamond tooling and/or has strict requirements on subsurface damage, surface impurities and grain structure. As a production process, it can be used to reduce manufacturing costs where large numbers of ultra-precision, repetitive designs are required and produce parts out of hazardous materials without generating added waste.

1 Coining Apparatus

To minimize complexity, the system was engineered to constrain all degrees of freedom except rotation and displacement. Tight control of parallelism and angular motion between the coining die surfaces reduces the requirements for precise near-net-shape blanks. The mechanical design provides high angular stiffness, reducing the chance of copying non-parallelism into the final product. The body, or housing of the unit is stiff and compact to mitigate the effects of temperature and

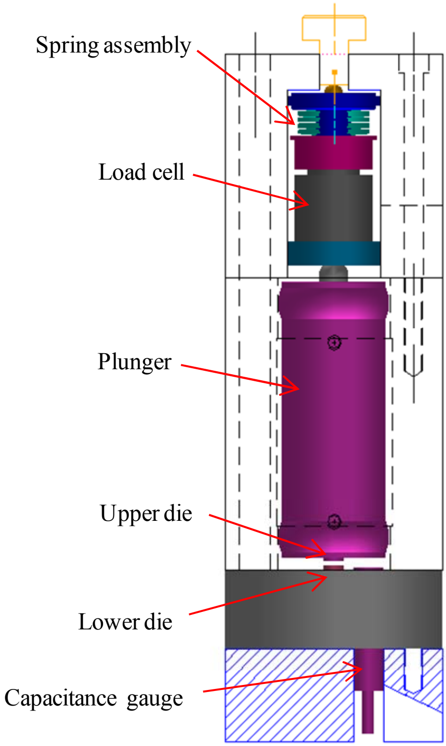

Figure 1: Schematic image of the instrumented precision coining press.

compliance and acts as a guide for the die plunger. To provide a smooth surface and clearance (2.5um) for contaminants the bore is machined on a diamond turning lathe using a single point diamond (SPD) tool. After boring, without disturbing the machining set-up, the body's critical face is surfaced as illustrated in Figure 2. This provides less than 7 arc second angular misalignment between the die and the guide bore that constrains the die plunger.

The die plunger contains two ultra-precision, diamond turned torroidal guide bearing surfaces. The plunger is designed to transmit load, guide the die and act as a reference surface for measuring displacement . The bearing surfaces and die face are SPDT on-axis, in the same machining set-up. This turning and facing-to-center routine is preferable when producing products requiring one planar surface.

The punch plate supports and orients the aluminum housing and is fitted with the ultra-precision punch blank. For coined products requiring planar or 1D features, the profiled punch can be machined (diamond turned) off-axis in a lathing operation. Figure 2a shows an elevation view of the machining set-up were located on opposite sides of the face-plate (for balance). The total error sources for the entire coining system should minimize wedge or TTV to less than .10um (for products less than 3mm in diameter).

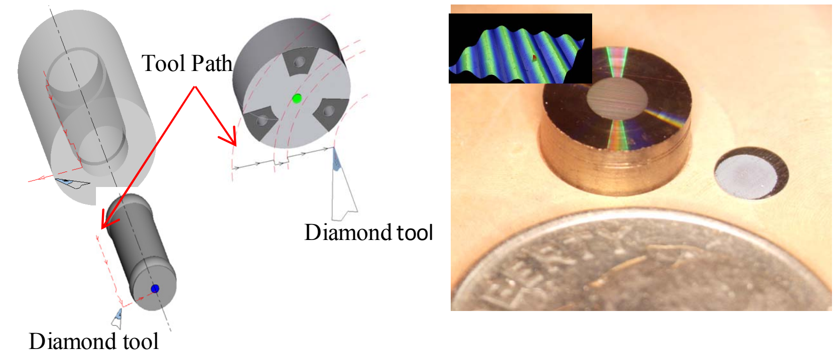

Figure 2: a) Forming the die profile is done in a single operation to ensure parallelism of the two faces. This helps mitigate thickness variation of the final part. b) Image and 3D profile of the diamond turned nitride steel die with a 4 µm peak to valley 50 µm spatial wavelength sine wave.

2 Die Manufacture

The ultra-precision, contoured coining dies profiles are produced by single-crystal diamond turning. The requirements for coining deep, detailed features into hard materials has lead to researching die materials that include heat treated electroplated nickel phosphor coatings and nitrided steel layers. While diamond machinable amorphous electroless nickel platings are limited to Vickers hardness of approximately 550 HV, thermo-chemical modified high-alloyed tool steel surface layers reaches Vickers hardness of approximately 1200HV. This can be done by a newly developed heat-assisted nitriding process altering the chemical composition of the subsurface zone of the steel substrate material [3]. After nitriding, a diamond machinable surface layer with a thickness of up to 30 µm can be used for diamond machining processes. Here, for example in single point diamond turning of nitrided carbon steel (42CrMo4) a surface roughness of better than 10nm Sa..

3 Coining A Refractory Metal

Our initial efforts have focused on coining micrometer features in 50 µm thick tantalum. Being a refractory metal, tantalum does not machine well under normal circumstances and the surface finish requirements of the finished part were less than 50 nm Sa. In addition, modification of the bulk material due to mechanical polishing and/or work hardening had to be minimized relative to the pre-coined state. To assist in the forming of the micrometer features, the complete coining assembly was raised to 200 C° for approximately 8 hours to lower the flow stress [4-5]. Figure 3 shows and example of a 3 mm diameter coined section of pure Ta with the specified micrometer surface feature and surface finish.

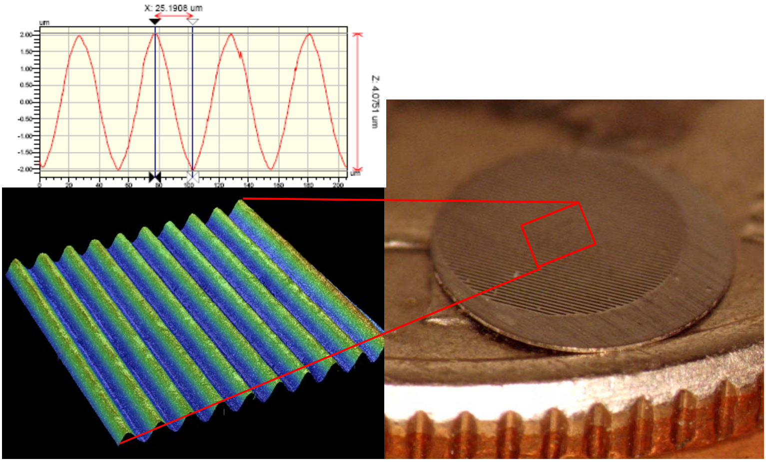

Figure 3: Forming the die profile is done in a single operation to ensure parallelism of the two faces. This helps mitigate thickness variation of the final part.

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